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Author(s): Karen S. Cook, Richard M. Emerson, Mary R. Gillmore, Toshio Yamagishi
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The Distribution of Power in Exchange Networks: Theory and Experimental Results

Karen S. Cook, Richard M. Emerson, Mary R. Gillmore, and Toshio Yamagishi
University of Washington

This paper presents a theoretical analysis of the structural determinants of power in exchange networks, along with research findings from laboratory experiments and a computer simulation of bargaining in network structures. Two theoretical traditions are dealt with: (1) point centrality in graph-theoretic representations of structure, as an approach to power distributions; and (2) power-dependence principles applied to exchange networks. Measures of centrality available in the literature have the advantage of being easily applied to large and complex networks. In contrast, power-dependence concepts were conceived for use in microsociology and are found to be cumbersome in the analysis of complex networks. But despite the relative difficulty of applying power-dependence theory to network structures, that approach generates hypotheses about power distributions which are confirmed at nearly every point in a laboratory experiment with five-person networks and at every point in a computer simulation of networks too large for laboratory study. In contrast, centrality measures applied to the type of networks studied fail to predict power distributions. Although centrality measures might predict power in some networks, their generality is limited. Toward resolution of the issues raised, this study offers two theoretical points: (1) a distinction between two different principles of "connection" in social networks suggests that current measures of centrality might predict power in one type of network but not in the other; and (2) it offers a first step toward a fusion of power-dependence theory and structural centrality in a way which might be general across networks of both types.

A review of the literature in sociology and anthropology over the past 15 years would show a virtual explosion in research dealing with social networks. This explosion is partially a result of the rapid improvement during this time period in the methodology for analyzing network data

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(see, e.g., White, Boorman, and Breiger 1976; White and Breiger 1975; Burt 1976). Theoretical developments, however, have lagged behind methodological advances, so much so that Granovetter (1979) was prompted to caution that a "theory gap" exists. One reason for this state of affairs is that network methods have not been tied closely to existing bodies of sociological theory. More commonly, network properties have been examined descriptively (e.g., in detailed analyses of particular individuals' personal networks) or have been treated as variables to be "added to" other sets of factors in the explanation of some particular behavior (e.g., voting behavior, health-seeking behavior). Even the sophisticated techniques developed to render complex data sets analyzable (i.e., blockmodeling techniques) give us primarily new methods for detecting social structure, not a "theory of social structure."

Furthermore, the devices we use to represent networks—such as points, lines, edges, and geodesics—and the concepts we use to describe network properties—such as density, centrality, and degree of connectedness—are devoid of specific substantive meaning. A point can be a person, an organization, or any other entity, and a line can represent anything that can occur between two points (e.g., a friendship link, a business transaction, the flow of information, influence, resources, or energy). This abstractness has facilitated formal mathematical analysis, for example, the development of graph theory (Harary, Norman, and Cartwright 1965); but, as Foster (1979), Freeman (1979), and others have suggested, it has frequently presented problems in the interpretability of findings.

In this article we attempt to articulate theory concerning exchange networks with structural concepts drawn from recent work on social networks. Stimulated by Freeman's (1979) thoughtful essay, we focus on centrality and its relation to power in networks of connected exchange relations. Using important theoretical distinctions taken from exchange theory (Emerson 1972), we demonstrate that in certain types of exchange networks existing measures of structural centrality (as identified by Freeman 1979) have limited utility in predicting the locus of network power. Empirical work of this type can help not only to clarify the link between centrality and power but also to identify the limitations of existing measures of centrality and to suggest fruitful directions for the development of more general theory. First, we introduce relevant theoretical notions; then we describe empirical results and present conclusions concerning centrality and the distribution of power in exchange networks.

EXCHANGE NETWORKS: BASIC CONCEPTS

Many of the social networks of interest to social scientists can be analyzed fruitfully as exchange networks, provided that the specific content of the social relations in the network involves the transfer of valued items (i.e., the provision of information, affection or approval, advice, or more tangible things like goods and direct services; see Sarason et al. [1978] on this point). The concept "exchange network" has the theoretical advantage of allowing the extension and application of already well-developed dyadic conceptions of exchange (e.g., Homans 1961, 1974; Emerson 1962, 1972) to more macro, *N*-actor levels of analysis.

On the basis of Emerson's (1972) earlier work, an exchange network can be defined as consisting of: (1) a set of actors (either natural persons or corporate groups), (2) a distribution of valued resources among those actors, (3) for each actor a set of exchange opportunities with other actors in the network, (4) a set of historically developed and utilized exchange opportunities called exchange relations,[2] and (5) a set of network connections linking exchange relations into a single network structure. Thus an "exchange network" is a specific social structure formed by two or more connected exchange relations between actors, with "connection" defined as follows:

> *Definition 1:* Two exchange relations between actors A-B and actors A-C are connected to form the minimal network B-A-C to the degree that exchange in one relation is contingent on exchange (or nonexchange) in the other relation. (*a*) The connection is positive if exchange in one relation is contingent on exchange in the other. (*b*) The connection is negative if exchange in one relation is contingent on nonexchange in the other.

The importance of an explicit theoretical treatment of the concept "connection" in any theory of social networks has not been fully recognized. That any two dyads, A-B and A-C, have one member in common (i.e., actor A) does not necessarily imply that these two relations are connected and thus represent a three-actor network. As a result, for exchange networks, common membership is not sufficient as a "connecting principle." If the A-B and A-C exchange relations are connected (by definition 1), they define the minimal network or component, B-A-C, of possibly larger structures, each such component being either positively or negatively connected within itself. Larger network structures might therefore consist of purely positive connections, purely negative connections, or some mixture of both types.

The distinction between negative and positive connections has significant theoretical implications for network analysis which have yet to be fully developed. For example, the discussion thus far has said nothing about the social conditions producing one or the other type of connection.

[2] The set of exchange relations is properly viewed as a subset of exchange opportunities. Members of an exchange relation are assumed to have some degree of "commitment" to the relation, relative to other potential alternatives (see Cook and Emerson [1978] regarding commitment).

Generally speaking, one expects that if B and C are alternative exchange partners for A, in the sense that B and C are substitutable as sources, then the connection is negative.[3] Alternative sources thus introduce an element of negativity or competition (see Cook 1978) into the exchange system. Dating networks and friendship networks are typically negatively connected throughout. On the other hand, if a resource obtained from B is required by A for interaction with C (e.g., as when A is a broker), the connection at A is positive. Large networks completely positive in form are probably very rare because of the frequent existence of alternative sources. "Mixed" structures, we suspect, are much more common. For example, exchange in the Kula ring, described by Malinowski (1922), involves a specific complex pattern including exchange connections of both types (see Emerson 1981). Similarly, larger networks involving brokers typically entail both positively and negatively connected exchange relations. Marsden's (1982) simulation of "brokerage" is a study of "mixed" networks.[4] For both substantive and analytical reasons, we begin our investigation with a focus on purely negatively connected networks.[5] However, research concerning purely positively connected networks and mixed networks is currently under way.

The concept "network connection" allows us to specify the boundaries of concrete networks and develop a theory in which events happening at any location in the network have predictable repercussions within the boundaries of the network. The concept of connection and the distinction between two basic types[6] is one of the primary features distinguishing the

[3] In addition to specifying the conditions under which different types of connection are likely to emerge, it is theoretically interesting to specify the mechanisms which alter the nature of the connection. For example, a negative connection might be transformed into a positive connection through "product differentiation" or some other type of resource value differentiation. Well-known examples of these types of processes exist in economics (e.g., product differentiation) and sociology (e.g., division of labor or role differentiation).

[4] While Marsden's (1981*a*, 1981*b*, 1982) work is based on Coleman's model of exchange, the particular interest and control structures he specifies in his simulation (Marsden 1981*b*) combine to produce elements of both positive and negative connection in the networks he investigates.

[5] The exact character of the connections forming natural social networks must be determined by research directed to that end. That is our major point in introducing the concept. Given the difficulties such field research can encounter, it is essential to develop theory regarding network connections. Laboratory research, in which networks connected in known ways can be created and studied, has much to offer in the development of such theory. That the networks established in our laboratory resemble in exact detail no "real" network should neither surprise nor bother the reader. External validity is, of course, an important concern. This means that definitions and propositions which can be applied both inside and outside the laboratory must be developed through our efforts at theory construction. We have reason to believe that, when that is done, laboratory work can inform field research.

[6] In addition to the sign of the contingency (positive vs. negative) linking exchange relations, it is important to note that network connections can vary in strength We will not develop a quantitative concept of connection in this article

exchange approach to network structures from other theories or methods of network analysis. While exchange networks have empirically determined boundaries, often the actors themselves are not aware of those boundaries. For example, in a three-actor network, B-A-C, actors B and C might not even know of one another. Similarly, A might have no knowledge about possible network relations beyond or between B and C. This has important implications for the analysis of social structure. Frequently there are no consensually defined network boundaries, even though boundaries do exist. Thus, participation in a network typically is not based on "membership status." Instead, actors can be viewed as relatively autonomous decision makers occupying "positions" in a structure which frequently extends beyond their own awareness.

Position in an Exchange Network

For simplicity, an exchange network can be represented as a digraph (see Harary et al. 1965; Berge 1962) or as a flow network (Harary et al. 1965; Busacker and Saatz 1965). Points in a network graph represent individual or corporate actors; lines or edges represent exchange relations. We use the notion of "residual graph" from graph theory to specify what we mean by position in a network. A residual graph (or matrix) is obtained by the removal of a specified point from a parent graph. The use of this concept allows us to locate sets of actors (identified as points in the graph) who have structurally similar locations in a network. We refer to these actors as occupants of the same position. Thus, we define position in graph theory terms as follows:

> *Definition 2:* A position in a graph or network is a set of one or more points whose residual graphs are isomorphic.

The concept "position" is important for two reasons: (*a*) it helps simplify the analysis of otherwise more complex networks, and (*b*) it has been demonstrated to be an important determinant of behavior in exchange networks (see Cook and Emerson 1978). Figure 1 portrays some of the network structures studied in our laboratory. Letters identify network positions, and numerical subscripts represent individual actors as occupants of each position.

In the networks shown in figure 1: (1) if each actor has a resource which the other actors value and each actor values all other actors' resources, (2) and if each line represents an opportunity to exchange these valued resources, (3) then the patterns of lines displayed in this figure can be considered exchange "opportunity structures." Any opportunity actually used will involve a mutually beneficial two-way transfer or exchange of resources. Within these opportunity structures, over time, networks of connected exchange relations emerge. In our laboratory research the experimenter determines the opportunity structures shown in figure 1. The subjects in these network studies conduct exchanges within the constraints set by the opportunity structure, forming exchange relations and a network of exchange through their actions. In the particular structures diagramed in figure 1, solid lines represent more profitable exchange opportunities than broken lines (by a factor of three to one); thus some opportunities will be experienced as clearly more beneficial than others. The less favored opportunities should not lead to the formation of continuing exchange relations. Therefore, the actual networks expected to emerge are those represented by the solid lines in figure 1. These emergent networks are negatively connected. If an actor has two solid-line opportunities, the two partners represented are fully interchangeable as sources of benefit. With finite exchange time available, any use of one opportunity means that another opportunity is forgone.

An important feature of our laboratory research is that the actors located in the structure have no knowledge of the network beyond their own opportunity set. Thus in figure 1, positions A, C, D_2–D_4, and E_3–E_8 are all identical from the occupants' viewpoint. But, as positions in a network, they differ from each other in one respect—the nature of the remote structure they are embedded in, which transcends the occupants' knowledge. This feature allows us to examine "purely" structural deter-

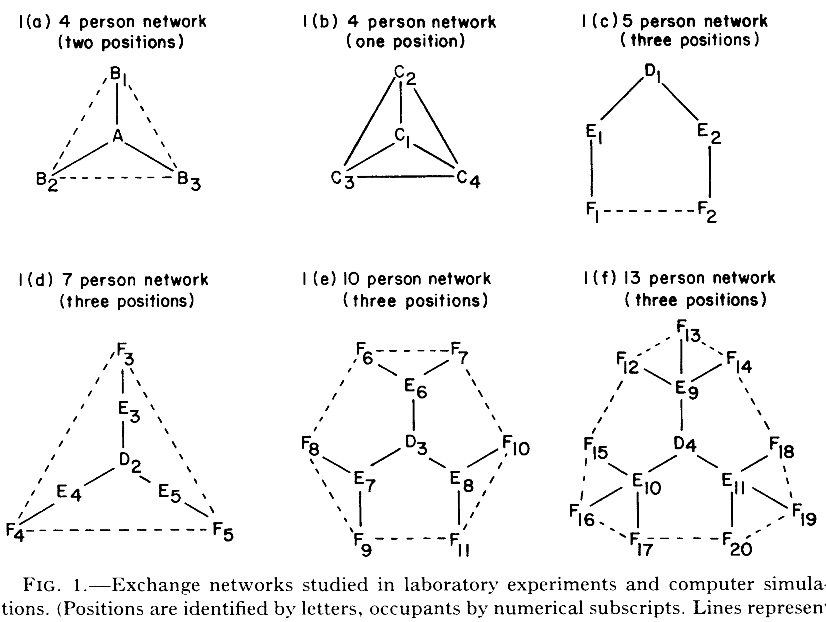

FIG. 1.—Exchange networks studied in laboratory experiments and computer simulations. (Positions are identified by letters, occupants by numerical subscripts. Lines represent the negotiated exchange of 24 points [solid lines] or eight points [dashed lines].)

minants of behavior. In particular, the distribution of power can be studied as a function of position in an opportunity structure. Furthermore, if we let the actual amount of resources exchanged in any given transaction be determined by negotiation, so that benefit, while mutual, is potentially unequal, power use can be measured in terms of the actual benefits obtained through negotiation.[7]

CENTRALITY AND POWER IN NEGATIVELY CONNECTED EXCHANGE NETWORKS

In a previous experiment (Cook and Emerson 1978) on the distribution of power in negatively connected exchange networks, the structures diagramed as figure 1*a* and *b* were studied. The results concerning power use demonstrated that power is a function of position in the network, even when the position occupants are ignorant of the actual network structure and their own position in it. More specifically, power was found to be concentrated in position A, the most central position, relatively absent in the peripheral position B (see fig. 1*a*), and evenly distributed across the occupants of position C (in the power-balanced network, fig. 1*b*).[8] The outcome of that experiment was predicted on the basis of simple power-dependence reasoning (i.e., A is less dependent than B and C_i and C_j are equally dependent). But the results could have been predicted parsimoniously on the basis of structural centrality, if power is hypothesized to be a function of centrality. Thus the question arises, Do predictions based on power-dependence notions and those based solely on structural centrality yield the same results in negatively connected networks? We turn to two bodies of theory and an experiment to provide an answer. The network diagramed in figure 1*c* is the one analyzed in the actual experiment. Simulation results are presented for networks 1*d–f*. In order to examine the generality of the link between centrality and power in negatively connected exchange networks, we moved to the analysis of larger, more complex networks in which not all actors have direct access to one another and no actor enjoys simple monopoly power (as A does in fig. 1*a*).

[7] In order to examine power use we removed from the situation factors known to inhibit the exercise of power. For example, actors in a network were not informed about the profits of other actors in the network. This procedure effectively removes the operation of equity concerns from the negotiations (see Cook and Emerson 1978).

[8] The comparison between these two networks can be considered an empirical comparison between a "star" network (fig. 1*a*) with maximum point centrality (i.e., one clearly dominant position) and an "all-channel" or completely connected network (fig. 1*b*) in which access is equalized across the network. Marsden (1981*b*) would refer to these two types of networks as "restricted access" vs. "open access" networks, respectively, with "access" referring to access to highly valued resources.

Point Centrality

Structural centrality is one of the most frequently discussed properties of networks.[9] Freeman (1979) identified three major conceptions of point centrality, each associated with a different underlying measurement approach: degree-based measures, betweenness measures, and closeness-based measures. A degree-based measure (see Nieminen 1974; Freeman 1979) is a count of the number of adjacencies for a point. As Freeman (1979, p. 221) notes in the context of communication networks, "The degree of a point is viewed as an index of its potential communication activity." Betweenness measures are based on the "frequency with which a point falls between pairs of other points on the shortest paths [or geodesics] connecting them" (Freeman 1979, p. 221). Points central in this respect exhibit potential for control, since according to Freeman (1979, p. 221), strategic location on paths linking pairs of points provides potential influence in communication networks through the "withholding or distorting of information in transition." Finally, closeness-based measures (e.g., Sabidussi 1966) give an index of the extent to which a particular point is "close" to all other points. This is a distance measure that counts the number of edges or lines in the paths (or geodesics) linking two points. Centrality in this case is indexed by the "shortest" distance score of one point to all others. Freeman (1979, p. 224) interprets this measure (or set of measures) as an indicator of the extent to which a point can "avoid the control potential of others." In the case of communication networks a "central" point, being close to other points, is less dependent on intermediaries for relaying information. Freeman concludes his article by stating that substantive concerns must determine the appropriateness of a particular conception and measure of centrality.

For some networks these three types of measures give the same results with respect to identification of the most central point. For example, all agree that the center of a "star" configuration is most central (e.g., point A in fig. 1*a*). However, in other types of networks there is marked departure from agreement in the assessment of point centrality. For example, even in the fairly simple networks in figure 1*c*–*f*, there is some variation in the predictions regarding point centrality. Closeness and betweenness measures consistently identify point D as the most central position. Thus an ordering of point or position centrality based on these two types of measures suggests: D > E > F in networks 1*c*–*f*. Different orderings can

[9] Two general centrality notions have been developed: (*a*) "point centrality" or dominance and (*b*) "graph centrality." We will consider only measures of point centrality since we are interested primarily in the comparison of positions "Relative" measures of point centrality will allow us to compare results across networks of different size. Graph centrality, which gives one measure of the degree of centralization of the entire network, may prove useful for other purposes

occur when a degree-based measure, counting only adjacencies, is used. Degree-based measures suggest the following orderings of positions with respect to centrality in these same networks: (1) for networks 1*c* and 1*e*, D = E > F; (2) for network 1*d*, D > E > F; (3) for network 1*f*, E > D > F.[10]

The major conceptual weakness of this measure is that it is highly localized: it takes into account only direct links, not indirect effects or paths. Thus the other two measures are superior for our purposes because they take into account the total structure of the network by focusing on characteristics of the paths or geodesics which link all pairs of points in the graph. Since our primary interest is in centrality as a network-wide indicator of power, we set aside degree-based measures as theoretically inadequate for the task. That leaves closeness and betweenness measures as potentially useful conceptions of centrality in exchange networks. The virtue of these measures is that, unlike the dyadic conception of power-dependence theory, these measures of centrality incorporate the entire structure into the centrality score assigned to each position. Thus centrality is a theoretical direction worthy of close scrutiny in experiments on more complex networks (e.g., fig. 1*c*–*f*).

Centrality has been defined as one of the most important characteristics of positions, not only in communication networks (see, e.g., Bavelas 1948, 1950; Leavitt 1951; Shaw 1954, 1964; Mackenzie 1966) but also in sociometric networks (see, e.g., Moreno 1934, 1943) and interorganizational networks (see, e.g., Rogers 1974; Miller 1980; Mizruchi and Bunting 1981). Thus it is logical to examine its role in exchange networks. Interest in point centrality has been fueled partially by the empirical demonstration that power and influence seem to be a function of the centrality of one's position in a social system (see Hopkins 1964). For example, Marsden and Laumann (1977, p. 217) state that "those persons at the center of the network, on whom the more peripheral actors are dependent, are the most powerful actors in the system." In other work (see Laumann and Pappi 1973, 1976), this finding is referred to as the principle of "integrative centrality." Marsden and Laumann (1977, p. 224) also note that "power as computed by the Coleman model reflects the relative centrality of an actor in a network of dependency relations." The parallel use of the terms "centrality" and "dependency" in the work cited is noteworthy. Their relation to one another is the basic focus of this theoretical section.

If power is indeed a function of centrality, measured in terms of closeness or betweenness, then we arrive at the following experimental hypothesis concerning the link between power and centrality in the negatively

[10] Centrality scores based on degree-, betweenness-, and closeness-based measures can be computed easily for each network position in fig 1*c* (see Freeman [1979] for computations).

connected exchange network graphed in figure 1*c,* the object of the experiment reported here:

> *Hypothesis 1:* In the network portrayed in figure 1*c,* D > E_i > F_j in power if either closeness or betweenness-based measures of point centrality are used.

This same prediction holds for the networks diagramed in figure 1*d–f,* tested in a series of simulation experiments reported below.

We do not offer hypothesis 1 with theoretically based confidence. Instead, we offer it because (*a*) structural principles are desirable in order to advance exchange network theory, (*b*) point centrality appears to be the best currently available candidate because of its relation to power, and (*c*) this hypothesis makes explicit the predictions which the best measures of point centrality would make, if applied to the networks under study here. Since we are dealing with negatively connected exchange networks (as in the previous experiment reported in Cook and Emerson [1978]), we are especially interested in the general applicability of centrality notions to predictions concerning the locus of power in this type of network. It is important to note that many centrality measures were originally developed to apply to networks in which resources (or bits of information) flow through intermediary points. In our negatively connected networks, however, the flow of resources is between two adjacent actors (i.e., points) with no intermediary; that is, there is a direct as opposed to an indirect exchange of resources. If point-centrality measures do not predict well in negatively connected networks, either centrality is not linked to power in such networks or these measures are limited to certain kinds of networks and we must specify more carefully the substantive meaning of existing measures of centrality. Freeman (1979) concurs. Such specification is necessary if we are to develop a more general theoretical conception of centrality which accommodates qualitatively different types of networks.

POWER AND DEPENDENCE

While the relation between power and centrality is intuitively compelling, it has not been given an explicit theoretical interpretation. As a step toward that end, we return to power-dependence theory. The following definitions are taken, with minor modifications, from Emerson (1962, 1972):

> *Definition 3:* In any dyadic exchange relation A_x; B_y (where A and B are actors, and x and y are resources introduced in exchange), the power of A over B (P_{AB}) is the potential of A to obtain favorable outcomes at B's expense.

> *Definition 4:* The dependence (D_{AB}) of A on B in a dyadic exchange relation

(e.g., A_x; B_y) is a joint function (1) varying directly with the value of y to A, and (2) varying inversely with the availability of y to A from alternate sources.

On the basis of Emerson's arguments (1962, 1972), we assert the following fundamental relationship between power and dependence: $P_{AB} = D_{BA}$.

Power-dependence concepts deal with the distribution of power between two partners in a dyadic exchange relation; thus they are not well suited for analyzing the power distribution among positions in an extended network. However, in very simple networks of the sort studied in the laboratory, power-dependence analysis can be applied, one relation at a time (and only one relation at a time), across the network. The results of this analysis yield three unambiguous predictions concerning the locus of power in these negatively connected networks. The predictions are as follows:

Hypothesis 2: As the exchange process proceeds through time, the occupants of position E will display more power use than the occupants of positions F and D. This display of greater power use will take two forms: (*a*) an increase over time in the amount of benefits received from exchange at position E, and, as a result, (*b*) a greater absolute level of exchange benefit obtained by the occupant of position E by the final exchange phase.

Hypothesis 3: The differential power use of E over F will be displayed before the power use of E over D (since the latter process is, in theory, predicted to be a result of E's power use over F).

Hypothesis 4: In the final or stable phase of power use, the occupants of position E will exert equal levels of power over the occupants of positions F and D.

According to these hypotheses, the predicted ordering of positions with respect to power in these networks at equilibrium is $E > D = F$, which contradicts the prediction based on point-centrality measures (hypothesis 1).

The reasoning behind these predictions follows directly from power-dependence principles and the concept, exchange connection, when they are applied to all of the dyadic relations in the network. First, in negatively connected networks, any two lines joined at a point provide that point with "alternative sources" of value, as stated in definition 4. Therefore, if the relative value of resources is held constant (as in our experiment),[11] the structure of the network determines the relative dependencies throughout the network. Second, while positions D and E have equal access to

[11] By "constant" we simply mean that the value is assumed to be the same across the conditions in our experiment. This assumption is reasonable since, although it is obvious that values vary across individuals, if subjects are assigned randomly to network positions as well as experimental conditions, there should be no systematic differences by condition.

resources, each having two valuable partners, their partners do not have equal exchange opportunities. In figure 1*c*, unlike D, E_i has one very dependent partner over whom he or she has power and from whom, therefore, he or she will obtain high benefits assuming that E_i uses power in a "rational" way.[12] As a result, D's apparent power equality with E_i (based on an equal number of alternatives) will be short lived, for D must compete with F_j for access to E_i and F_j has no alternatives. Stated analytically, F-E-D is a negative connection or purely negative component, as are all the connections in these networks. Thus, D (the occupant of the central position) is ultimately as weak as all of the F_j (peripheral actors), with E_i emerging as the most powerful. These predictions hold even when none of the actors has knowledge about the network beyond his own immediate partnerships.

Reasoning from power-dependence theory can be carried still further. In definition 4, two variables govern dependence. One of these, the availability of valued resources, operates through position when network structures are involved, resulting in a social structural determinant of power. That is, position in the network determines availability. The other variable governing dependence, the relative value of the resources introduced at various positions, was held constant in the above predictions. If resource value is allowed to vary—as it does in nature—then it will confound the foregoing network structural determinants of power. However, if one varies resource value between networks while holding it constant (either high or low) within networks, still another hypothesis can be advanced.

If the incentive to exchange is high (because the resources exchanged are highly valued) throughout the network, then position will create differentials in resource availability; the latter determine dependence and thus power. Predictions 2, 3, and 4 assume some incentive to exchange. In contrast, if the incentive to engage in exchange is uniformly low, no actor in the network will be very dependent on the others and the potential power inequalities will be reduced across the network regardless of position. Therefore,

Hypothesis 5: The effects implied in hypotheses 2, 3, and 4 will be more

[12] This assumption is necessary theoretically since it allows us to derive testable predictions concerning manifest power from principles dealing with potential power. In our experimental setting, by "rational" we mean that each actor in the network explores alternative sources of benefit in the network (*a*) through extending offers to others and (*b*) by comparing offers and counteroffers from others. Each actor maximizes benefit by (*a*) accepting the better of any two offers, (*b*) lowering offers when offers go unaccepted, and (*c*) holding out for better offers when it is possible to do so. This is clearly a testable assumption, but all one could conclude from evidence to the contrary is that sometimes subjects in our laboratory act "irrationally." We have examined empirically some of the conditions under which these conditions do not hold (e.g., when equity concerns are operative; see Cook and Emerson [1978]).

pronounced under conditions of high exchange incentive than under conditions of low exchange incentive.

POWER AS POTENTIAL, POWER USE, AND EQUILIBRIUM

Power, in definition 3, is conceived as a potential for gaining increased benefit at the other's expense in a dyadic exchange relation. In applying this conception of power to networks of negatively connected exchange relations, we have seen above that the structure helps determine that potential for each position in the network, but the occupants of these positions might use their power in varying degree or at a variable rate. If power is ever used to its theoretical limits, then, in our research setting, the less powerful actor could receive no more benefit from the more powerful actor than is obtainable from the best alternative source. This would define the theoretical equilibrium point.

Considering the structures in figure 1, if solid lines represent 24 units of profit to be divided through exchange and dashed lines represent only eight units of negotiable profit, then the best alternative source for all occupants of position F is fixed at four points (8/2). Thus, if power were exerted to its absolute maximum in these networks, all occupants of position E would obtain 20 points per exchange, while all occupants of positions F and D would obtain four points per exchange when equilibrium is reached (i.e., when the exchange ratios have stabilized). If there are restraints on the exercise of power (e.g., equity concerns or less than fully rational negotiation), equilibrium will be reached somewhere short of this maximally "exploitive" exchange ratio (see Cook and Emerson 1978).

But regardless of the particular equilibrium point reached over time in any specific network, the rate at which power use approaches the equilibrium level will be a function of the relative availability of resources to the actors in the network (i.e., their relative dependencies). This is a direct extension of power-dependence reasoning which can be investigated in our laboratory. Let us develop this reasoning and then derive hypotheses to be examined in a series of simulation experiments conducted on networks 1*c*–*f*.

What varies across these networks is not only the size of the network, but, more important, the relative availability over time of highly valued resources to the occupants of positions D and E_1. Relative availability of resources from alternate sources determines relative positional dependence (see definition 4). Relative positional dependence across the network of connected exchange relations determines power as evident in the chain of reasoning developed above (e.g., hypotheses 2–4). As a function of F_1's dependence on E_1, the relative availability to D of valued resources from

E declines over time (even though D and E have an equal number of alternate sources).[13] Thus D's dependence on E_1 increases, with the result that E's power over D increases (since $P_{ED} = D_{DE}$). The outcome of this process is a reduction of power at the "center" in these networks. This chain of reasoning based on the rather cumbersome application of dyadic power-dependence notions and the concept of negative connection yields fairly clear predictions concerning the rate at which equilibrium is reached in the distribution of power in these exchange networks:

> *Hypothesis 6:* E's use of power over D will emerge more slowly in network 1*d* than in network 1*c*.

This prediction is based on the fact that the increase in the number of alternatives for D in network 1*d* increases the availability of resources to D and thus may result in an initial power advantage for D over E, but the advantage will be eroded over time as predicted above, because of the decreasing availability of valued resources from E. This decrease should occur later in network 1*d* than in 1*c*, retarding somewhat E's rise to power in 1*d*. Furthermore, it can be predicted that:

> *Hypothesis 7:* E's use of power over F will emerge more quickly in network 1*f* than in 1*e*, where it will emerge more quickly than in 1*d*.

This prediction results from the decrease in dependence of E_1 on F_1 across these three networks. The dependence of F on E_1 is not altered across these networks, but E gains power over F to the extent that the resources F_1 has to offer are available from other sources (i.e., other F_j). In addition, as stated in hypothesis 3 above, E_1 will display a power advantage over D based indirectly on E_1's power over F. Thus it follows from hypotheses 3 and 7 that, since E's power over F is emerging more rapidly across these networks, E's power over D should also emerge more rapidly. Therefore:

> *Hypothesis 8:* E's use of power over D will emerge more rapidly in network 1*f* than in 1*e*, where it will emerge more rapidly than in 1*d*.

An important point to be made is that treating number of alternatives as a perfect indicator of resource availability can result in erroneous predictions when applied to connected sets of exchange relations and suffers from the same deficiency as a simple degree-based measure of

[13] Various theorists (see Blalock and Wilken 1981; Marsden 1982) treat number of alternatives as the main determinant of dependence (along with resource value). While this may seem to be implied by Emerson's (1962, 1972) definition of dependence, it is important to note that the operative term is "resource availability," which only under certain conditions translates directly into number of alternatives. As one anonymous reviewer cleverly stated, "It makes no difference how many bad sources of supply a position has." Thus it is important to distinguish theoretically between resource availability and the number of resource suppliers.

centrality. In theory, availability and number of alternatives must be kept analytically separate even though under certain conditions number of alternatives may completely determine availability (e.g., as in the case of a network in which there are no indirect paths).[14] Thus, in network 1*d*, for example, position E is predicted to emerge as more powerful than D over time, despite the fact that D has access to more alternative exchange partners and appears to occupy a more central location in the network.

THEORETICAL STRENGTHS AND DEFICIENCIES

Before we turn to experimental results, deficiencies in both of the theoretical approaches we have explicated should be noted. The issue before us in the following experiment is not which approach makes correct predictions in this case but, rather, how best to integrate network-structural principles and power-dependence theory to explain the dynamics of power in exchange networks. The difficulty with power-dependence concepts, as they now stand (e.g., Emerson 1962, 1972), is that they are too closely bound to dyadic analysis. The reasoning behind hypotheses 2, 3, and 4 is complex as a result. Yet, within this limitation, power-dependence theory has the virtue of being closely coordinated with concrete behavioral concepts and observations. Furthermore, it offers an intuitively appealing theoretical interpretation of the notion of centrality. Marsden and Laumann (1977), and others, as noted above, have attempted to relate dependency notions to power and centrality in networks. Power-dependency theory may help accomplish this task.

In contrast, the approach to power through point centrality of positions has the virtue of taking the structure of an entire network into account in specifying at once a degree of centrality (and thus a power level) for every position in that structure. Because of the formal mathematical properties of networks, such analysis can be applied to very complex structures. But this approach is weak where the other one is strong. The link between centrality and power is largely intuitive; and the abstract graph-theoretic networks to which these centrality measures have been applied are only loosely coordinated with the social interactive networks they represent. For example, the concept of connection, which is so fundamental in our substantive theory of networks, to our knowledge has not been incorporated in any formal network model. As a result, previous approaches cannot make differential predictions concerning the locus of power in positively and negatively connected networks. Thus we did not

[14] For example, in a star network all peripheral actors have direct access to one and only one source of valued resources. Adding more peripheral actors to the network simply increases the number of suppliers to the central actor; it does not alter the relative dependence of those on the periphery (unless there is a very finite supply of resources at the center).

design the following study as a "critical" test between two bodies of theory. Instead, we hoped to gain an empirical base for further theoretical development which would facilitate the integration of these two research traditions.

THE EXPERIMENT

An experiment was designed to test the foregoing predictions derived from point-centrality and power-dependence notions. The experiment was conducted in a computerized laboratory, using methods described more fully in Cook and Emerson (1977, 1978).

Briefly, subjects were recruited from undergraduate classes and campus newspaper ads. Emphasis was placed on the desire to earn money as a motive for taking part in the experiment. After a brief collective orientation, each subject was taken to a private room containing a computer terminal. All terminals are joined to a minicomputer in the laboratory which is programmed to allow certain terminals to communicate with certain other terminals. This procedure gives the experimenter control of the network of exchange opportunities.

Within the opportunity structure set by the experimenter, subjects negotiated with one another for "profit points" by sending offers and counteroffers until trade agreements were reached. Each transaction involved the division of a constant sum of points (either 24 or eight as shown in fig. 1) between two bargaining partners in that transaction. However, the subjects did not know the constant sum and therefore could not compare their own with the other's benefits. In this way principles of "equity" were effectively prevented from operating in this laboratory setting.

The total time of 81 minutes spent in the exchange process was divided into 27 transaction periods of 180 seconds each. Each person was allowed to complete only one transaction per period. Therefore, the network created in the laboratory was negatively connected: exchange in one relation was contingent on nonexchange in other relations during a given transaction period. That is, the use of one exchange opportunity meant that other opportunities had to be forgone during that time period.

Design Features

The experimental design involved the following features:

Network structure.—The network shown in figure 1*c* was used. Five persons in one network were treated as one experimental case or data unit.

Measurement of the dependent variable, power use.—In each exchange relation in the network (shown as a solid line in fig. 1), two persons negotiated over the division of 24 points convertible into dollars. The use of power of one person relative to the other is measured as the number of points obtained through negotiation.

Incentive manipulation.—The manipulation of exchange incentive was straightforward. Both the amount of fixed wages the subjects would receive during the experimental session and the value of the profit points they could obtain by completing trade agreements were varied. These conditions were operationalized as follows: (1) In the high-incentive condition, subjects were paid $0.25 per hour while each profit point obtained through exchange was worth 2.5¢. As a result, most of their pay was derived through exchange. (2) In the low-incentive condition, the fixed wage for participation was $3.00 per hour and the value of each point was 0.5¢. Subjects in this condition therefore derived most of their pay through a fixed wage and were less dependent on making exchanges in order to derive pay.

Design.—The design of the experiment was a factorial type containing two between-subjects variables: (1) exchange incentive (high vs. low), and (2) subject gender (male vs. female). There was one within-subjects variable: trial blocks (there were 27 trials aggregated into three trial blocks each containing nine trials). Within each sex, subjects were randomly assigned to experimental conditions including positions within networks. Five cases were included in each cell of the design (a case is a five-person group).[15]

Subjects.—A total of 100 university students (50 male and 50 female) took part in the study described as an investigation of negotiated trade agreements.

RESULTS

Manipulation Check

As a partial check on the exchange incentive manipulation, subjects were asked on the postexperimental questionnaire to indicate how important earning money through exchange was for them. The results of a two-way (sex × incentive) analysis of variance on this item indicated a significant main effect for incentive ($F = 8.17$, $df = 1,96$, $P < .01$). The means ($\bar{X}$)

[15] Eight subjects were scheduled per session to insure that the subjects would not discover the identity of their bargaining partners. The extra three subjects, randomly selected from the eight, participated in a three-person replication experiment. The orientations for both experiments were identical and the computerized system allowed us to run more than one experiment simultaneously. The subjects knew only that they would have two exchange partners randomly selected from the seven others present and were not aware that two experiments were being run. Thus, they did not know the exact size of the networks or the nature of the exchange connections among the remaining participants.

indicated that the importance of earning money through exchange was greater for subjects in the high-incentive conditions than for those in the low-incentive conditons ($\bar{X}$ = 5.42 vs. $\bar{X}$ = 4.52 on a seven-point scale where 7 represents extremely important). No other effects were significant.

Power and Network Position

If power is indeed a function of point centrality, then, assuming actors use their power, the occupants of position D should evidence more power use than the occupants of the more peripheral positions, E and F. However, on the basis of power-dependence principles, we predicted in hypothesis 2 that occupants of position E would emerge as most powerful. Hypothesis 2 implies two findings: (*a*) a systematic increase over time in the amount of profit E is able to obtain in exchanges with both D and F, and (*b*) ability on the part of E to obtain better than half the total profit available per dyadic exchange with both D and F (i.e., E should be able to obtain significantly more than 12 points per exchange on the average since there are 24 points available for each exchange involving E).[16] Furthermore, hypothesis 5 predicts that these power differences will be more pronounced under conditions of high exchange incentive than under conditions of low incentive.

The profit data for E's exchanges with both D and F in network 1*c* under conditions of high and low exchange incentive are displayed in table 1. To test the hypothesis that E's profits from exchanges would increase over time, separate three-way analyses of variance (incentive × sex × trial block) for designs containing a repeated measure were performed on the profit obtained by E in exchanges with both D and F. As implied by hypothesis 2*a,* a significant main effect for trial blocks was obtained for the former (E's exchanges with D: $F = 3.34$, $df = 2{,}32$, $P < .05$) as well as the latter (E's exchanges with F: $F = 5.89$, $df = 2{,}32$, $P < .05$). Inspection of the cell means in table 1 indicates that these effects were due to an increase in the profit received by E over time as predicted by hypothesis 2*a*.

Hypothesis 5 implies that this increase in E's profits over time will be greater under conditions of high exchange incentive than low incentive.

[16] Since we are interested primarily in the effect of network position on the exercise of power, no distinction is made in our analyses between exchanges involving different occupants of the same position. The data for occupants of identical positions were averaged. For example, the profit obtained by E in exchanges with D was calculated as the average profit obtained by E_1 and E_2 in all dyadic exchanges with D. Similarly, the profit obtained by E in exchanges with F was calculated as the average profit of E_1 and E_2 obtained in all dyadic exchanges with F_1 and F_2.

In other words, the interaction of incentive and trial blocks should be significant. For E's exchanges with D, this interaction effect was significant ($F = 3.69$, $df = 2,32$, $P < .05$). Inspection of the trial means in table 1 indicates that this effect was due to the differential rate of profit increase over time in the two incentive conditions as predicted by hypothesis 5. For E's exchanges with F, however, the interaction was not significant.[17] Thus hypothesis 5 received support in the case of E's exchanges with D but not with F.

Since the emergence of power use is expected to occur over time, only data from the last trial block were used to test hypothesis 2*b*. As predicted by this hypothesis, E's profits in exchanges with D were significantly greater than 12 ($\bar{X} = 15.26$, $t = 2.75$, $df = 19$, $P < .01$, one-tailed test). Similarly, E was also able to obtain significantly greater than 12 points in exchanges with F ($\bar{X} = 16.18$, $t = 6.46$, $df = 19$, $P < .01$, one-tailed test). Thus, hypothesis 2*b* received clear support.

Hypothesis 5 implies that the profits received by E should be greater under conditions of high incentive than low incentive in exchanges with

TABLE 1

EXPERIMENTAL RESULTS:
MEAN PROFIT OF PERSON E PER EXCHANGE WITH D AND WITH F in NETWORK 1*c* BY EXCHANGE INCENTIVE AND TRIAL BLOCK

Exchange Incentive and Exchange Partner	Trial Blocks 1	2	3
Low:			
D	13.80	12.69	13.32
	(4.13)	(4.26)	(4.25)
F	13.27	14.78*	15.44**
	(3.10)	(2.77)	(2.96)
High:			
D	12.90	13.72	17.19**
	(3.71)	(4.40)	(5.26)
F	15.52**	16.66**	16.91**
	(2.38)	(2.10)	(2.46)
Combined:			
D	13.35	13.21	15.26**
	(3.95)	(4.36)	(5.16)
F	14.40**	15.72**	16.18**
	(2.99)	(2.63)	(2.82)

NOTE —The profit obtained by D and F in negotiations with E can be obtained by subtracting the values in this table (E's profit) from 24 Standard deviations are in parentheses
* Significantly greater than 12 ($P < .05$)
** Significantly greater than 12 ($P < .01$)

[17] This result may be due to a "ceiling" effect. The exchange rate seems to stabilize in the high-incentive condition at about 16 to eight by trial block 2, approaching but not reaching its theoretical maximum. This same rate of exchange was also approached in the low-incentive condition but stabilized later (i.e., in the third trial block).

both D and F. To test this aspect of the hypothesis, E's profits in the low-incentive condition were compared with E's profits in the high-incentive condition. For E's exchanges with D, this difference was significant ($\bar{X} = 3.87$, $t = 1.72$, $df = 18$, $P < .05$, one-tailed test). However, for E's exchanges with F, the difference was not significant ($\bar{X} = 1.47$, $t = 1.15$, $df = 18$, N.S.). Once again, hypothesis 5 was supported for exchanges with D but not with F (see n. 17).

Differential Emergence of Power Use over Time

Hypothesis 3 predicted that the power use of E over F (the most peripheral position) would be displayed first, followed by the emergence of power use by E over D (the most central position), because occupants of position F are more dependent initially than the occupants of position D. To test this hypothesis, a difference score was computed by subtracting the points obtained by E in exchanges with F from the points obtained by E in exchanges with D for the first trial block. A *t*-test for correlated means indicated that this difference was not significant ($\bar{X} = 1.04$, $t = 1.17$, $df = 19$, N.S., one-tailed test). However, by the second trial block, when power use had begun to emerge, the difference was significant ($\bar{X} = 2.51$, $t = 3.19$, $df = 19$, $P < .01$, one-tailed test). Thus hypothesis 3 was supported. (This hypothesis makes no claim about *when* power use will emerge; it claims only that it will emerge earlier in exchanges with F than in those with D.)

Hypothesis 5 implies that the differential emergence of power use of E over F and D predicted in hypothesis 3 will occur earlier under conditions of high exchange incentive than under conditions of low incentive. To test this hypothesis, a difference of differences score was calculated (i.e. $[\text{Profit}_{EF} - \text{Profit}_{ED}]_H - [\text{Profit}_{EF} - \text{Profit}_{ED}]_L$, where the first difference is obtained from the high-incentive condition and the latter from the low-incentive condition). For the first trial block this score was significant ($\bar{X} = 3.14$, $t = 1.88$, $df = 18$, $P < .05$, one-tailed test); it was not significant for the second trial block ($\bar{X} = 0.84$, $t = 0.52$, $df = 18$, N.S.). This finding suggests that the differential in power use by E over F relative to E's use of power over D emerged earlier under conditions of high incentive than under low-incentive conditions as implied by hypothesis 5.

Equal Powerlessness of the Central and Peripheral Positions

Hypothesis 4 predicted that, in the final phases of the exchange process, occupants of the most powerful position, E, would be exercising an equal amount of power use over both D and F. This implies that the profits E obtains from D will not be significantly different from those E obtains from F in the final trial block. The hypothesis assumes, however, that the exchange process has stabilized. As a check on this assumption, E's profits for the first and second halves of the final trial block were compared. If the exchange process has stabilized by the last trial block, there should be no significant difference between E's profits in the first and second halves of this final exchange phase. For the high-incentive condition, this was true ($F = 0.01$, $df = 1,16$, N.S.). However, the difference was close to significant in the condition of low exchange incentive ($F = 3.80$, $df = 1,16$, $P < .07$). This suggests that under conditions of low incentive, the exchange process may not yet have stabilized; hence we shall test hypothesis 4 only for the high-incentive condition. A t-test for correlated means revealed no significant difference between the amount of profit E received in exchanges with D and that received in exchanges with F in the high-incentive condition ($\bar{X} = 0.28$, $t = 0.19$, $df = 18$, N.S.); the test confirms hypothesis 4.

Hypothesis 5 implies in addition that the equality in the level of E's use of power over D vs. F will emerge more quickly under conditions of high than of low incentive. To test this implication, E's profit from exchanges with D versus F under high incentive was compared with E's exchange profits from D versus F under low incentive. This "difference of differences" approached significance, indicating that the predicted equality of power use by E over D versus F (i.e., hypothesis 4) tended to be achieved earlier under the condition of high exchange incentive ($t = 1.38$, $df = 18$, $P < .10$, one-tailed) than under that of low exchange incentive.

These results taken together provide strong support for the basic predictions derived from power-dependence reasoning concerning the distribution of power over time in negatively connected exchange networks. All of the primary hypotheses (i.e., hypotheses 2–4) were supported. Hypothesis 5, concerning the effects of differential levels of exchange incentive, was partially supported. In general, the effects predicted in hypotheses 2–4 were stronger under conditions of high exchange incentive than under those of low exchange incentive. Even when the predicted differences did not obtain (e.g., for hypothesis 2), the results suggest that the effect of low exchange incentive was to delay E's use of power over D, whereas F's dependence was so great that the exchange incentive made no difference in the emergence of E's use of power over F (see table 1). The emergence of E's power over D is, in theory, predicted to occur subsequent to the emergence of power over F (see results for hypothesis 3). Thus, E's power differential over D may not have had sufficient time to emerge in the low-incentive condition before the end of the experiment. The findings concerning the lack of stabilization (see hypothesis 4 results) of the exchange process during the final trial block under low incentive further support this contention.

COMPUTER SIMULATION OF MORE COMPLEX EXCHANGE NETWORKS

Having demonstrated empirically the predictive power of power-dependence theory within network 1*c*, we turn now to predicted differences in power use among the networks in figure 1*c*–*f*. Hypotheses 6, 7, and 8 present these predictions. Because laboratory experiments with such large networks are too costly to conduct, we developed a computer simulation to "test" these hypotheses. Because hypotheses 1–4 apply to all of the more complex networks as well as to network 1*c*, the generality of those predictions was also explored in the simulation.

A program (labeled SIMNET) was written to simulate the negotiation of exchange among actors in any negatively connected *N*-actor network.[18] The program has the capacity to vary the size and "shape" of the network, the number of trials, the amount of profit available for various exchange relations, the number of offers and counteroffers permitted within a given trial, and the "toughness" of the simulated actors (i.e., their tendency to drive relatively hard bargains). For consistency with the assumptions underlying power-dependence theory, the simulated actors were programmed to act "rationally," that is, to attempt to maximize their profits through the exchange process. As in the theory presented above, the "power" of these simulated "actors" can derive only from their location in the network, which links them to identically programmed other "actors."

"Rationality" in this bargaining program means specifically that each actor: (1) accepts the better of any two offers, (2) raises "its" demand the next time if its offer has been accepted, and (3) lowers its demand when an offer goes unaccepted. When an actor receives an offer which is greater than the one it is currently seeking, the actor increases its demand the next time; it decreases its demand when the incoming offers are lower than its own past demands. The initial offers (or demands) sent out by the simulated "actors" at the beginning of the first trial were randomly assigned within the range of 1–23. Initial offers of 0 and 24 were not allowed, nor were negative demands. The initial offer was sent to all the exchange partners for any given actor. At the beginning of subsequent trials, the initial demand of each actor was increased if an exchange had been completed on the previous trial or decreased if the actor had failed to complete an exchange on that trial.

[18] The simulation program was written in FORTRAN on a PRIME 300 mini-computer by one of the authors, Toshio Yamagishi. Details concerning the program can be obtained by writing this author.

To test our predictions, we simulated the 5-, 7-, 10-, and 13-actor networks in figure 1*c–f*. The number of transaction periods, or trials, was twice that used in the experiment, or 54 trials, to allow us to examine any trends which might be produced over a longer period of time. For each network structure, 50 replications were conducted, so that $N = 50$. We present the results in table 2, which shows the average points obtained by E_i from F_j and D in each network structure across six trial blocks of nine trials each.

Simulation Results

Simulation results can be examined in two ways: (*a*) for evidence that the simulation program is realistic, and, if there is such evidence, (*b*) as "data" to support or contradict our hypotheses.

a) Simulation of the five-person network in figure 1*c* allows a direct comparison with the results obtained from human subjects. The simu-

TABLE 2

SIMULATION RESULTS:
MEAN PROFIT OF THE POWERFUL (E) PER "EXCHANGE" WITH D AND WITH F IN FOUR REPLICATIONS VARYING NETWORK SIZE

Figure Part, Size of Network, and E's Exchange Partner	Trial Blocks					
	1	2	3	4	5	6
1*c*, 5 actor:						
D	12.79a	15.36	17.15	18.60	19.31	19.55
	(2.57)	(2.76)	(2.98)	(2.11)	(1.67)	(1.44)
F	14.71	16.33	17.83	19.08	19.86	19.91a
	(2.64)	(2.76)	(2.56)	(1.86)	(1.42)	(1.26)
1*d*, 7 actor:						
D	10.56b	13.03	15.00	16.54	17.64	18.47
	(3.02)	(3.07)	(2.81)	(2.32)	(1.68)	(1.43)
F	14.33	15.31	16.64	17.79	18.66	19.06
	(2.95)	(2.34)	(2.40)	(1.93)	(1.38)	(.97)
1*e*, 10 actor:						
D	13.99	17.69	19.65	20.06	20.11	20.11
	(2.89)	(2.37)	(1.07)	(.58)	(.55)	(.54)
F	16.35	18.68	19.86	20.11	20.22	20.01
	(2.16)	(1.35)	(.59)	(.42)	(.43)	(.39)
1*f*, 13 actor:						
D	14.50a	19.56c	20.42	20.63	20.50	20.43
	(3.18)	(2.10)	(.86)	(.66)	(.64)	(.55)
F	17.18	20.06	20.67	20.87	20.69	20.58
	(1.69)	(.74)	(.57)	(.59)	(.52)	(.49)

NOTE.—These values represent the average profit E obtained in "exchanges" with D and F, with 24 units of profit available for each "exchange"; therefore D's and F's average profit equals 24 − E's profit in each case. Each trial block contained nine trials. Cell values are based on the simulation of 50 groups; in an occasional group, however, E did not complete an "exchange" in a given trial block. Cell means labeled "a" are based on 49 groups, that labeled "b" has 47 groups, that labeled "c" has 42 groups per cell; all others have 50 groups per cell. Standard deviations are in parentheses.

lation results in table 2 reproduced the entire pattern of experimental results in the high-incentive condition. (The low-incentive condition was not simulated.) Hypotheses 2, 3, and 4 are supported both by real and by simulated subjects. These parallel findings can be used to infer both the "rationality" of our real subjects and the "realism" of SIMNET.

b) An examination of table 2 shows that all of the relevant hypotheses advanced through the application of power-dependence theory were supported by the simulation results. Specifically, the power of E over D emerged more slowly in network 1*d* than in 1*c* where D had fewer alternatives, as predicted by hypothesis 6. However, when the number of alternatives for D is constant, the rate at which equilibrium occurs depends on the number of alternatives for E, as indicated by hypothesis 8 and supported by the data in table 2 for the relevant networks 1*d*–*f*. Similarly, as predicted by hypothesis 7, the power of E over F emerged more quickly as the number of E's alternatives increased (networks 1*d*–*f*). Thus, while D and F_j are shown to be equally powerless in the long run, the rate at which this equilibrium condition was achieved differed systematically as specified by hypotheses 6–8.

DISCUSSION: POWER, DEPENDENCE, AND CENTRALITY

The findings obtained both from human subjects in a simple network (fig. 1*c*) and from the simulation of more complex networks demonstrate clear support for the predictions based on power-dependence theory. In contrast, two of the best conventional measures of point centrality (closeness and betweenness) fail to generate sound predictions concerning the distribution of power in negatively connected exchange networks. As a result of these findings, we arrive at two major conclusions. First, if we are to retain the intuitively appealing notion that power is a function of centrality, we must either develop a more general conception of centrality or apply current measures of point centrality only in certain types of networks.[19] For reasons of theoretical parsimony and generality, the former strategy is preferred. Second, while we have shown that power-dependence theory provides a very good basis for predicting the distribution of power in these networks, the theory was originally formulated at a very micro level ill-suited to the analysis of complex network structures. Therefore, power-dependence theory needs to be raised, if possible, to a more macroscopic level of analysis.

[19] One solution is to specify theoretically the conditions under which different measures of centrality apply. Freeman (1979) has begun this task. However, the logical conclusion to such efforts might well be the increased proliferation of centrality measures For the sake of parsimony, it would be preferable to develop more general conceptions and measures of centrality

Power-dependence theory (Emerson 1962, 1972) examines the power of one actor over another on the basis of the dependence of the latter. It is therefore fundamentally dyadic. What is needed is the determination of power at a position within a structure, on the basis of the "dependence" of the entire structure on that position. We suggest (*a*) that a measure of such system-wide dependence on a given position in the network will turn out to be a measure of the "centrality" of that location and (*b*) that power at this location can be interpreted easily in power-dependence terms. Furthermore, we suggest that such a dependency-based concept of centrality may be general, applying across all types of exchange networks, whether negatively connected, positively connected, or mixed. In this section of the discussion we can only point out the basic features of this approach, leaving a complete formulation for later work.

Dependence and Network Vulnerability

We start with this basic question: to what extent does the flow of valued resources (information, economic goods, political patronage, etc.) within an *N*-actor network depend on facilitating exchange behavior by the occupants of a given position in that network? Stated differently, to what extent will reduced participation or exchange activity at a given location have detrimental consequences for exchange throughout the network?

Our first step toward a theoretical solution to such questions was prompted by the graph-theoretic concept of "vulnerability"—the vulnerability of the network (or graph) to the removal of a given point or line (Harary et al. 1965). By "removal" we mean substantively any form of withdrawal from exchange activity. To remove a point (P_i) from a graph (G) is to obtain a subgraph called a "residual graph" (RG_i). Compared with the parent graph (G), the structure of the residual graph (RG_i) might be "weakened" or impaired in terms of resource flow, in which case the parent graph G is said to be "point vulnerable" at P_i. We suggest here that the contribution of P_i to the network G and the "dependence" of exchange in that network on P_i can be studied by comparisons between G and RG_i. Since we have defined a position as a set of points whose residual graphs are isomorphic, there need only be as many G and RG_i comparisons as there are positions in the network structure (i.e., residual graphs for points occupying the same position in a network are identical). These comparisons will provide a measure of the "dependence" of the network as a whole on each position therein.

While a large number of more or less complex and refined measures can be derived from comparison of a graph with its residual graphs, one simple measure using the network in figure 1*c* (reproduced below for convenience) will serve to illustrate.

With this network taken as graph G, the three residual graphs shown in figure 2 are formed by the removal of points from positions D, E, and F, respectively. In our experiment, 24 resource units were exchangeable along solid lines and eight units along broken lines. From that information we can calculate what we refer to as the Reduction in Maximum Flow (RMF) in the total network which would result if a given point were removed. The results are shown in table 3. By this measure our laboratory network appears to be vulnerable only at position E, the position shown to be most powerful both in the actual experiment and in the simulation findings.

Vulnerability in a negatively connected network locates the points of minimum dependence, equivalent to maximum network-wide power. Even though in these networks there are no "indirect" paths of resource flow

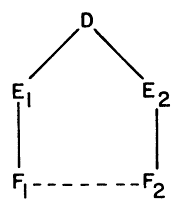

FIG. 1c.—Five-person network (three positions)

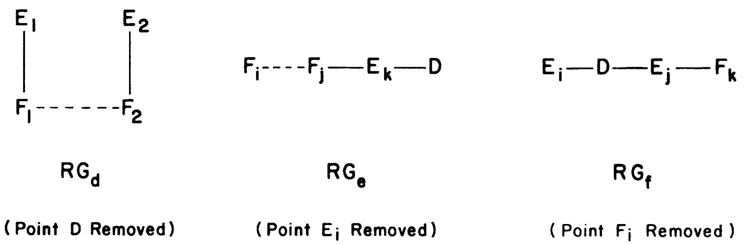

FIG. 2.—Residual graphs formed by the removal of points from positions D, E, and F respectively in network 1c (graph G).

TABLE 3

REDUCED MAXIMUM FLOW AS A MEASURE OF NETWORK VULNERABILITY AT EACH POSITION IN THE EXPERIMENTAL NETWORK 1c

Graph	G	RG_d	RG_e	RG_f
Maximum flow rate*	48	48	32	48
Reduced maximum flow (RMF)	...	0	16	0

* Maximum resources exchangeable in the network per transaction period.

as there would be in a positively connected network, the volume of resource flow within exchange relations is dictated both by accessibility to exchange partners and by the availability of resources from those partners. Thus positions are relatively "powerless" in a network (e.g., D in network 1*c*) to the extent that they have few exchange opportunities (i.e., few alternative sources of valued resources) and have direct connections only to actors who have highly reliable alternative sources of supply. In any network of exchange, availability of resources from exchange partners is critically determined by the nature of their connections to other sources of benefit. Thus while there are no indirect paths of resource flow (e.g., indirect exchange) in negatively connected networks, there are indirect effects of the structure of the alternative exchange opportunities, and these effects have repercussions throughout the network. These are structural implications of the nature of the exchange connections. It is important to note that the overall structure determines the distribution of power in negatively connected networks which do not involve resource flows across the entire network. The distribution of benefit, however, is dictated by the distribution of power even though the actors have no awareness of the total potential benefit to be obtained in the system through exchange activity.[20]

We have developed only a first approximation of a general measure of network-wide dependence on a given actor (or point).[21] This discussion is meant only to illustrate the theoretical potential of a "vulnerability" approach to the problem of raising power-dependence theory from a dyadic to a more macrostructural level of analysis. At a minimum this conception achieves identification of the centrally located positions in networks which are negatively connected.

System-Level Dependence and Centrality

This conception of vulnerability can also be seen as a useful approach to the measurement of point centrality in an exchange network that is sensitive to the nature of the connections that join dyads into networks. If the networks depicted in figure 1*c* and *e*, for example, were positively connected at E_1 (i.e., if E_1-F_1 exchange were contingent on E_1-D exchange), the removal of D would greatly reduce the network capacity for resource

[20] Since the actors do not have knowledge of the total potential gain possible through exchange activity, the exercise of power by any actor in the structure is a function of position in the network and not of any direct knowledge or awareness of his potential to thwart the "efficient" (or maximizing) distribution of resources across the network.

[21] The RMF measure requires modification if it is to be applied to digraphs (see Yamagishi 1981).

flow[22] (i.e., D is a point of vulnerability in this network). For E_1 to continue to receive resources of value from F_1 in the network, E_1 would become dependent on D to maintain the flow of these resources to position E. Thus resource flow in the network as a whole would be highly dependent on D, returning power to the "center" in this positively connected network.

A "betweenness" measure of point centrality in positively connected networks is consistent with this vulnerability notion (as a measure of network-wide dependence on a point). As Freeman (1979) notes, what is at issue theoretically in communication networks is the potential for control through "withholding or distorting information." By extension to positively connected exchange networks, this concept would refer to the potential control over the rate of resource flow (i.e., through the potential to withhold resources or the failure to transmit them to other exchange partners in the network). While space will not allow a complete analysis of positively connected networks here, it does appear that the general notion of "vulnerability" can be adapted to positively connected as well as negatively connected networks (and, by implication, to mixed networks). What is interesting is that dependence and centrality clearly converge in this theoretical approach, as the choice of wording by Marsden and Laumann (1977, p. 224) would suggest. Further theoretical development and an experiment on positively connected networks are now in progress.

CONCLUSIONS

In this article we have dealt primarily with negatively connected networks, in an extension of previous research on the distribution of power in such networks. Our empirical research suggests that a very interesting structural principle applies to exchange networks of this type. It can be referred to as a "decentralization" principle: such networks tend to form into systems organized around multiple foci of power at the points E_1 in figure 1. Those points can be viewed as "regional centers" of power, like petty kingdoms in an encompassing empire (see Emerson 1982). Those points are defined as "central" if centrality is measured in terms of network-wide vulnerability at point P_1 (e.g., by a measure like the RMF measure developed here). But such points cannot be considered "central" in any sense of the term by any of the existing measures of point centrality without falling into circular reasoning concerning the relation of power to centrality.

[22] In a network of direct exchange relations like the one in fig. 1*a*, the removal of the central point (e g., A) completely halts profitable exchange activity, since the actors on the periphery cannot engage in a profitable exchange of resources.

Thus our research has identified a major weakness in existing point-centrality measures: they are not applicable to negatively connected exchange networks. To fill this gap, we developed a measure based on the concept of vulnerability, network-wide dependence on a particular point. More important, we have suggested that this general notion may be developed to apply to positively connected networks as well, since in networks of this type vulnerability seems to correspond to the underlying theoretical meaning of betweenness-based measures of point centrality (see Freeman 1979). Thus, it is reasonable to expect that in positively connected networks, "centralization" (i.e., a power shift to the center) is more likely to occur than decentralization because of the network-wide dependence on point D (if the connections are defined as positive instead of negative in fig. 1*c–f*). Position D in such networks serves as the only resource link among the various peripheral subsystems of exchange activity (e.g., E_1-F_1).

These notions are being developed further in order to specify theoretically the implications of the different types of exchange connections. It is clear that the integration of structural network principles with exchange network theory provides useful insights into the dynamics of power in networks of connected exchange relations. This type of theoretical activity will not only extend exchange theory but also provide one potential theoretical basis for network theory (see Cook 1982). Finally, this theoretical formulation offers an explicit procedure for linking actors' exchange behavior to network properties (Foster 1979) and suggests mechanisms which may yield "possible transformations" of these networks as a result of power dynamics or changes in the nature of the exchange connections.

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